

Predicting the Distribution and Properties of Buried Submarine Topography on Continental Shelves

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LONG-TERM GOALS

Compile geological data and develop methods to predict the distribution and properties of features hypothesized to be responsible for sonar geoclutter. Geological structures just beneath the seafloor, such as steep-walled channels, may have high-angle reflecting surfaces that can return false sonar alarms to ships operating in the littoral zone. The major goal is to contribute to the reduction or mitigation of geologic clutter observed on fleet sonar systems.

Two issues define the problem.

- Landscape forming issue: In area 'x', can the Navy expect geoclutter features and if so what are their sonar characteristics, i.e. channel orientation.
- Landscape burial issue: If geoclutter features are expected in area 'x', will the features be exposed or buried. Areas of low interest to the Navy include locations where Holocene deposits are thick. Areas of high interest to the Navy include locations where Holocene deposits are thin thereby allowing for the shallow burial of Pleistocene topography.

OBJECTIVES

- Define the character of different kinds of buried channels (size, shape, properties).
- Define the spatial distribution of these buried channels (river, tidal, hyperpycnal).
- Develop a global atlas of candidate geoclutter features and their characteristics.
- Develop and merge global databases of pertinent geological and oceanographic data.
- Develop predictive models and apply to margins of interest. Test predictive models in a known geoclutter rich area.
- Share and merge these databases, models and results with those in the Geoclutter Research Group working on tracking algorithms.

APPROACH

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1) Compile a global database of pertinent geological and oceanographic data, for use as initial inputs and constraints for models. Index the database by margin type, geographical area, climate conditions, shelf characteristics, and channel morphology. Include in the data base, shelf gradient and width, sediment type and distribution, channel morphology and infill, drainage architecture, adjacent river systems, morphology of river systems, relative sea level curves for geographic areas, wave climate.

2) Measure and analyze terrain attributes. Perform a comprehensive analysis of real and simulated elevation grids using RiverTools® and other GIS software. Calculate the geometric and statistical characteristics of landforms and how these characteristics vary from one geologic setting to another.

3) Classify terrain from geologic information. Classify “terrain types” in terms of the initial and boundary conditions (e.g. geology, erosion rates, excess rain rates) that produced the terrain types, using physics-based landform models (Peckham 1998, 1999). Solve the landform models numerically for (a) different sets of input parameters (e.g. rate constants) and (b) different sets of initial and boundary conditions (e.g. fixed or changing base level).

4) Determine the burial depth potential of low-sea level produced topography. Develop simple scaling relationships for deposition rate as a function of sediment input rates from rivers, wave and current conditions, and shelf geometry. Refine these bulk estimates with more detailed consideration of the nature of sediment delivery to the shelf (e.g., episodic storm-driven flooding vs. seasonal snowmelt flooding; the role of estuaries) and sediment redistribution, bypassing and deposition on the shelf (e.g., the long-term manifestation of short-term, episodic, storm-driven transport on the shelf).

5) Model the flux of sediment to and across continental shelves. Use process-based models to obtain a detailed consideration of the nature of sediment delivery to the shelf and sediment redistribution, bypassing and deposition on the shelf. Use *HydroTrend* (Syvitski et al., 1998; Syvitski and Morehead, 1999) to provide realistic estimates of the time varying nature of sediment flux from rivers, both under modern conditions and under paleo-conditions. Couple *2D-SedFlux* (Syvitski et al., 1999; Syvitski and Hutton, 2001) to fully integrated shelf sediment transport model and investigate shelf deposition under a variety of scenarios (changing river sediment input rates and timing, wave and current characteristics, sediment properties).

6) Compile a rendering of Holocene ocean currents and waves. Transport and deposition on the continental shelf depend on wave and current conditions, both functions of atmospheric conditions and bathymetry. Compare wind patterns from atmospheric paleoclimate models to modern conditions. Relate these changes in wind conditions to changes in wave conditions.

WORK COMPLETED

1) Acquired and began analysis on the results of CCM paleoclimate model experiments run at the National Center for Atmospheric Research (NCAR). The experiments predict precipitation, surface temperature, wind vectors and other climatic parameters for times: 3.5ka, 6ka, 8.5 ka, 11 ka, and 21ka. These times encompass the low-stand of sea level associated with the Last Glacial Maximum (LGM) and the subsequent transgression. The output is given at a spatial resolution of 10 degrees, and temporal resolution of one month. Statistics from these outputs will be used as climatic forcing in the *HydroTrend* hydrological model. High-resolution (3 arc second) dataset of merged topography and bathymetry of the U.S. East Coast obtained from the National Geophysical Data Center is used to test paleo-basins generated with the lower resolution global data. Collected Quaternary sea level curves at 300 global sites to address shoreline movements in addition to those exerted by eustatic fluctuations (Tushingham and Peltier, 1993). Data are based on radiocarbon measurements of particular diagnostic features of sea-level fluctuations, such as raised beach sequences and aggrading coral reefs.

Glacial extent for the LGM and more recent periods are constrained with output from the ICE-4G model (Peltier, 1993). The model predicts ice sheet growth in response to climatic forcing from paleoclimate simulations. Results of the model compare reasonably well to field investigations, although some significant discrepancies occur for Arctic Russia. The output from ICE-4G are being used to identify paleo drainage systems that are likely to have received significant glacial meltwater flux during the low-stand and transgression of eustatic sea level. The dataset is at a 1-degree spatial resolution.

2) Used modern bathymetry and topography at 2 min spatial resolution (Smith and Sandwell, 1997) to estimate paleo-basin dimensions and geometry for the portion of continental shelf exposed at the LGM (18 ka). Paleo-basins are defined with algorithms in the GIS package Arc/Info that use flow direction of a digital elevation model to map hydrologic drainage divides. The estimated paleo-basins provide boundaries by which to subsample climatic data that will feed into *HydroTrend*, to calculate the gross flux of sediment to the river's mouth in past times and constrain the location of sediment input to the paleo-shoreline. In addition, these paleo-basin boundaries will be examined with a "representation formula" for the general solution for a 3D steady-state fluvial landscape model. Such model landscapes have many features of interest, including peaks, ridges, saddles, channels, hillslopes and bifurcations (but no pits). A very fast computer program is just completed to implement this numerical method. The model has been used to solve several simple problems on a lattice of equilateral triangles. For problems with more intricate boundary conditions, numerical instabilities have been encountered. A commercial program called PDE2D is being used to help understand the nature of the instabilities, and to generate fluvial landscape solutions with dendritic branching patterns.

3) Explored a method (ANUDEM) developed by Hutchinson (1996) to fit "hydrologically sound" surfaces to limited elevation data on points, transects and contours. The method uses "optimality" or "cost function" concepts that are extremely similar to the "optimal surface" results for the steady-state fluvial landscape. The phrase hydrologically sound describes a surface that has well-defined drainage everywhere and no pits. Most surface-fitting algorithms, such as kriging, do not produce hydrologically

sound surfaces. The method should provide a fast and convenient way to reconstruct paleo-channel networks on the continental shelf from whatever elevation data is available.

4) The above datasets have been combined into GIS layers for easy selection and query for input into *HydroTrend*. Work is still in progress to make this process more automated. The empirical formula of Syvitski et al. (2000) is being used to compute the volumetric sediment discharge to a given coastline position. Similarly the volumetric water discharge is being computed from the paleo basin area to compute channel width, velocity and depth for channels which discharge to the coast.

5) Three shelf boundary layer models (VIMS, UVA, URS) are compiled on the INSTAAR ECI Facility. The VIMS and UVA models are imbedded and tested in *SedFlux*. The paleo conditions have been obtained from the NCAR-CCM paleoclimate model experiments that predict precipitation, surface temperature, wind vectors and other climatic parameters for times: 3.5ka, 6ka, 8.5 ka, 11 ka, and 21ka.

RESULTS

A steady-state landscape model is partly developed to reconstruct mud-buried channel networks on the continental shelf, and to establish empirical formulas that allow the geometric properties of channels and channel networks to be computed as functions of the physical input parameters to the model.

A result of numerically lowering sea level by 150m on a global DEM, with the intent of simulating LGM low-stand conditions, is that drainage patterns and distribution often differ from modern conditions. For example, paleo drainage basins derived from modern topography and shelf bathymetry. Three patterns emerge when the modern and simulated paleo basins are compared. Some basins maintain a similar size/shape to modern conditions, other river systems merge into a larger drainage system, and “new” drainage systems unrelated to modern systems are formed on the exposed shelf. The size of the Chang-Jiang (Yangtze) paleo basin appears similar to its modern size. However, the smaller Ping, Red, and Mekong Rivers may have merged into a very large river system that drained into the South China Sea. These predictions of paleo-basin dimensions on the now-submerged continental shelf are being tested against a dataset of channel distribution being compiled by N. Driscoll (SIO). Efforts are being made to validate the occurrence of river systems that may have merged their drainage networks. Areas of minor incision that would likely yield channel dimensions significant to producing geoclutter, are being identified.

IMPACT/APPLICATIONS

New numerical tools are being refined to allow for predicting the general nature of buried channels carved in to the seafloor during times when the sea level was as much as 120 m lower than observed today. The tools and databases will be coupled to acoustic models and used to assess acoustic reverberation and propagation. Because these tools are driven

by environmental data they offer the promise to provide seafloor acoustical information of continental margins at the global level.

TRANSITIONS

No transitions are completed at this early stage of the project. A Geoclutter meeting to be held in the fall of 2001 (Halifax NS) will provide a forum to transition some of our data and approaches to the US and NATO acoustic/sonar communities.

RELATED PROJECTS

ONR STRATAFORM: Scaling and Integration of Process-Response Stratigraphic Models.

ONR Mine Burial: Sediment Flux to the Coastal Zone: Predictions for the Navy.

ONR Uncertainty: Seabed Variability and its Influence on Acoustic Prediction Uncertainty.

NSF MARGINS: Experimental and Theoretical Study of Linked Sedimentary Systems.

NSF MARGINS: Community Sedimentary Model Science Plan for Sedimentology and Stratigraphy.

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